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Report on the United Nations/European Space Agency/Committee on Space Research Workshop on Data Analysis and Image-Processing Techniques

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Contents

		Paragraphs	Page
I.	Introduction	1-11	3
	A. Background and objectives	1-7	3
	B. Organization and programme	8-11	3
II.	Summary of presentations	12-54	4
	A. Remote sensing and geographic information systems: case studies	12-23	4
	1. Egypt: modelling the Western Desert environment using satellite data	12-13	4
	2. Libyan Arab Jamahiriya: land degradation and desertification	14-15	4
	3. Saudi Arabia: study of water resources in Al-Madinah al-Munawwarah	16	5
	4. Sudan: acquainting decision makers in developing countries with the potential uses of remote sensing technology	17-19	5
	5. Syrian Arab Republic: land use mapping and determining pollutant factors in the Al-Awage river basin using remote sensing techniques	20-21	6
	6. Syrian Arab Republic: remote sensing for agriculture and land resources	22-23	6

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B.	Remote sensing and geographic information systems: data analysis and image processing	24-43	6
	1. Digital image processing	24-25	6
	2. Use of remote sensing and geographic information systems in natural resource management	26-28	7
	3. Natural resource management using the geomatic approach	29-31	7
	4. Linear mixture modelling for vegetation mapping in dry lands	32-34	7
	5. Evaluation of texture-based classification of a single synthetic aperture radar image	35-36	8
	6. Combined classification of a SPOT-XS image using textural and multi-spectral information	37-42	8
	7. Role and retrieval of geophysical parameters in studying land surface processes	43	8
C.	Application of remote sensing in meteorology	44-47	9
	Overview of systems of operational meteorological satellites in geostationary and polar orbit	44-47	9
D.	Personal computer-based digital photogrammetry	48-51	9
E.	Hands-on remote sensing and geographic information systems at the General Organization of Remote Sensing	52-54	10

I. Introduction

A. Background and objectives

1. The Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), in particular through its Vienna Declaration on Space and Human Development, recommended that activities of the United Nations Programme on Space Applications promote collaborative participation among Member States at both the regional and the international level, emphasizing the development of knowledge and skills in developing countries.[1]

2. At its forty-third session, in 2000, the Committee on the Peaceful Uses of Outer Space endorsed the programme of workshops, training courses, symposiums and conferences planned for 2001.[2] Subsequently, the General Assembly, in its resolution 55/122 of 8 December 2000, endorsed the United Nations Programme on Space Applications for 2001.

3. Pursuant to resolution 55/122 and in accordance with the recommendation of UNISPACE III, the United Nations European Space Agency (ESA)/Committee on Space Research (COSPAR) Workshop on Data Analysis and Image-Processing Techniques was organized by the United Nations, ESA and the Government of the Syrian Arab Republic at the General Organization of Remote Sensing (GORS) in Damascus from 25 to 29 March 2001. GORS acted as host of the workshop on behalf of the Government of the Syrian Arab Republic.

4. The main objective of the workshop was to provide a forum for engineers, educators and scientists concerned with access, analysis and interpretation of satellite data. While the scientific and technical applications of satellite data may cover a wide range of topics, from environmental monitoring to astronomy and from meteorology to remote sensing, the basic techniques of satellite data processing with the necessary software are essentially common to those activities. The workshop studied data analysis and image-processing techniques so that the vast banks of such data that exist worldwide could be utilized by a larger number of engineers and scientists in developing countries.

5. The workshop provided a platform for interaction between engineers and scientists who generated satellite data for various scientific and technical applications and those, in particular in developing countries, who were involved in the access, processing, analysis and interpretation of satellite data for scientific research and practical applications in the areas of their expertise. The workshop equipped participants with an expert knowledge of the tools available for access, analysis and interpretation of data obtained by digital data acquisition systems for a variety of practical, educational and scientific purposes. Basic and advanced principles and methods were presented and reinforced with practical examples from everyday data access, analysis and interpretation operations. The workshop also fostered communication between users with a wide range of expertise in the production and use of software packages to pursue data management in remote sensing, geographic information systems (GIS), photogrammetry and their applications in natural resource management, in particular in monitoring water resources, desertification, land use, environmental pollution and ecosystem changes in arid areas.

6. The workshop also provided an opportunity to start preparations for the next workshop in the series, to be hosted by the Government of Nigeria, preferably at the African Regional Centre for Space Science and Technology Education—in English Language in Ile-Ife, Nigeria, in 2002.

7. The present report has been prepared for submission to the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space at its thirty-ninth session, in 2002. Participants have reported on the knowledge acquired and the work conducted during the workshop to the appropriate authorities of their Governments, universities and institutions. A number of papers presented at the workshop will be published in *Seminars of the United Nations Programme on Space Applications: Selected Papers from Activities Held in 2001* (ST/SPACE/7).

B. Organization and programme

8. The workshop was held at GORS, in Damascus, from 25 to 29 March 2001. It was attended by 56 engineers, educators and scientists from 15 countries,

Algeria, Austria, Egypt, Germany, India, Jordan, Lebanon, the Libyan Arab Jamahiriya, Morocco, Nigeria, Saudi Arabia, the Sudan, the Syrian Arab Republic, Tunisia and Yemen, as well as from the United Nations and ESA.

9. The United Nations and ESA provided financial support to defray the cost of international air travel and living expenses of 20 participants from developing countries. Room and board and local transportation for the same participants, as well as meeting facilities and equipment for the workshop, were provided by GORS.

10. The programme of the workshop had been developed jointly by the Office for Outer Space Affairs, GORS, ESA and COSPAR. Presentations made at the workshop covered satellite data analysis and image-processing techniques as used in the fields of remote sensing, meteorology and space science. Information on satellite data access, interpretation and archiving was also presented and demonstrations were made of appropriate software tools.

11. Opening addresses were made by representatives of GORS, the Office for Outer Space Affairs and ESA.

II. Summary of presentations

A. Remote sensing and geographic information systems: case studies

1. Egypt: modelling the Western Desert environment using satellite data

12. It was reported that Egypt had embarked on an ambitious project to reclaim land in the Western Desert, a part of the great African desert. The Toshka project would use the water resources of the Nile for reclaiming desert land. The project was also associated with agricultural activities for land reclamation, cultivation, food and agro-industrial activities, housing, transportation and supply of various forms of energy. The influence of climatic conditions on the above activities were not well documented or understood, but the arid environment and motion of sand dunes could greatly affect the sustained feasibility and economics of such activities. Proper climatic-related conditions, stressing appropriate use of passive and natural means, appeared to allow for better living conditions and also for considerable savings in the running costs of the project. However, such practices must rely on well-established and reliably verified environmental data suitable for design, monitoring and evaluation purposes.

13. The presentation described a proposal to use satellite data to construct a related sequence of environmental/climatic models suitable for use by the different activities mentioned at various levels of detail. That included macro-climatic, meso-climatic and simple micro-climatic model levels. The models incorporated digital image maps and meteorological databases to provide the basic model elements. A number of aerodynamic utilities, to provide surface wind speed and weathering conditions at selected sites, were integrated into the model for analysis and simulation purposes. The model relied heavily on modern techniques of data visualization to present model outputs for enhanced usability and user-friendliness. Coordination efforts with other entities working in related fields, such as desertification, meteorology, agriculture, architecture, archaeology, remote sensing and energy utilization, were a major concern of the proposal.

2. Libyan Arab Jamahiriya: land degradation and desertification

14. The presentation provided the background on available information concerning processes that caused and affected land degradation and desertification in the Libyan Arab Jamahiriya with emphasis on the Mediterranean coastal zone, where potential land for agriculture was located and where more than three quarters of the population were concentrated. National measures had been taken to combat desertification in the last four decades and further work was urgently required. An application of remote sensing and GIS to study land degradation of areas situated in the north-western region of the country was also included in the presentation. It indicated that scarcity of water (aridity), overgrazing and changing the range land to rain-fed agriculture had caused destruction of natural vegetation cover (reduction of bio-productivity and invasion of new species) and induced wind and water erosion. Increased human pressure on the use of localized underground aquifers caused sea water intrusion in the coastal zone.

15. In irrigated areas, the result of excessive irrigation and inefficient drainage had caused water logging and secondary salinization. Monitoring studies

in the El-Witia area (as a pilot project), which had been conducted at the Libyan Centre for Remote Sensing and Space Sciences in 1997, had shown the severe state of natural resource degradation in range lands of the coastal zone (52 per cent reduction in vegetation cover and 227 per cent increase in the formation of sand dunes over a 10-year period, from 1986 to 1996). Many measures had been taken to combat desertification in the last decades, including water development and conservation, wind and water erosion control, land reform, reclamation and development and several social and legal actions. Some of the past and ongoing anti-desertification measures taken had succeeded, while others were not suitable. Those measures must therefore be evaluated in order to provide a clear perspective for future programmes. The presentation also concentrated on the importance of modifying water resource policies so as to take into account the growing water scarcity in the country and the role of research, education and training in combating desertification and stopping land degradation more efficiently.

3. Saudi Arabia: study of water resources in Al-Madinah al-Munawwarah

16. The main objective of the study presented was the assessment of water resources in the city of Al-Madinah al-Munawwarah and its vicinity in order to find additional supplies of groundwater to meet the increasing demand for drinking water. Satellite images (including from the Landsat-5 thematic mapper (TM) and Système pour l'observation de la Terre (SPOT) satellites) had been processed to study the geology of the area. Three-dimensional images had been generated and used for detailed studies of the topography and water drainage systems. Geophysical surveys, including magnetic and resistivity surveys, had been made, as well as pumping tests of a number of water wells available in the area. That had been undertaken to discover the depth of the basement and hence the thickness of sediments as well as the depth and size of aquifers. Mathematical modelling had also been carried out to determine the current and future potential of aquifers. A number of sites that had drinking water potential and could be used to meet the increasing demand for drinking water had been located in the area under study. The project had been supported in part by the Al-Madinah al-Munawwarah Drinking Water Authority.

4. Sudan: acquainting decision makers in developing countries with the potential uses of remote sensing technology

17. It was stated that the Sudan, with an area of 2.5 million square kilometres, was the largest country in Africa, with diversified climates and natural resources. The utilization of those resources for a developing country such as the Sudan could be very difficult, as technology was at the heart of the development process. Thus, the need to utilize technology made the emerging use of remote sensing of vital importance, because it was one of the widely used advanced techniques. Whether on a local, regional or global scale, countries' demands for Earth resources were increasing rapidly. That situation required sound management of those resources, which could be attained by means of remote sensing.

18. The objective of the study was to acquaint decision makers in developing countries, and in particular in the Sudan, with the potential of satellite technology in obtaining vital information on crops, land use, marine and coastal environments, mineral exploration and so on and to emphasize the importance of such data in recent and future developments. The study had shown the application and usefulness of remotely sensed data for different natural resources and environmental aspects as a way of providing orientation for policy makers, planners, administrators and researchers. It has also revealed the need to use remote sensing for a developing country such as the Sudan, as it was a quick and practical tool for assessing, evaluating and monitoring the environment and natural resources. The results of integrating remote sensing in the Sudan into research, application and education would enhance the development of science and technology. Using remote sensing, it had been discovered that, in 1997, 18 per cent of the range lands in semi-arid regions of central Sudan had changed to cultivated lands, causing remarkable land degradation. In 1985, studies using remote sensing in western Kordofan had shown that no ecological zones had shifted southward; boundaries between different vegetation zones seemed to be the same as they had been 80 years ago.

19. The study recommended that the usefulness of remote sensing technology, augmented by GIS, for planning and development in developing countries be presented in a way that was convincing to decision

makers to support remote sensing applications. Most developing countries lacked the facilities for remote sensing. The study therefore recommended that those countries be provided with the necessary aid to establish remote sensing systems.

5. Syrian Arab Republic: land use mapping and determining pollutant factors in the Al-Awage river basin using remote sensing techniques

20. The objective of the study was to carry out an ecological survey for the Al-Awage river basin (which is considered one of the most important sources of water for Damascus) using remote sensing techniques and GIS. The study focused on the following issues:

(a) Vegetation distribution maps on the scale of 1:100,000 displaying the density and distribution of natural and cultivated vegetation cover in the basin region. The mapping also showed the correlation of vegetation presence with river water in three different combinations;

(b) Land use maps on the scale of 1:100,000, which made possible the determination of pollutants and other factors affecting the Al-Awage basin in general.

21. A number of recommendations and necessary proposals were submitted on the basis of the results of the study with a view to controlling pollution and to conserving and protecting both human health and the environment in the Damascus basin.

6. Syrian Arab Republic: remote sensing for agriculture and land resources

22. It was reported that remote sensing techniques had great importance in agricultural studies and land resource management. In that domain aerial photos and space images, which were recorded by electronic sensors or radar, were the tools that could be used to identify, monitor, assess and map agricultural wealth and land resources. Some of those activities were being carried out in the Syrian Arab Republic by GORS. The following case studies had been undertaken:

(a) Land use mapping in the west and south of the country;

(b) Land cover mapping;

(c) Soil survey and land classification in the west;

(d) Monitoring of land degradation in selected areas;

(e) Assessment of the land resources of the north-east;

(f) Range land monitoring and assessment in the Syrian grasslands;

(g) Forest mapping in the Syrian coastal mountains.

23. The studies had demonstrated that remote sensing was a valuable tool in such applications and that remote sensing and GIS integration was essential to establishing databases for agriculture and land resource management.

B. Remote sensing and geographic information systems: data analysis and image processing

1. Digital image processing

24. Digital image processing involved the manipulation and interpretation of digital images from remotely sensed data. In 1972, the United States of America had launched Landsat 1 and the digital image had become widely available for land remote sensing applications. There were various sources of digital image data, ranging from commercial Earth observation satellite systems, meteorological satellites and airborne scanned data to airborne digital camera data. All of those forms of data could be processed and analysed using digital image-processing software techniques.

25. Digital image processing often involved procedures that could be mathematically complex. However, the objective of the presentation was to introduce the basic principles of digital image processing. Digital image processing involved the following:

(a) Remote sensing data import;

(b) Radiometric correction;

(c) Geometric correction;

(d) Image enhancement;

(e) Image classification;

(f) Map generation (for output of maps).

2. Use of remote sensing and geographic information systems in natural resource management

26. It was pointed out that the rapid progress of remote sensing technology had made space data a very accurate and up-to-date spatial data resource that made it possible to prepare cartographic and thematic semi-detailed maps and to perform different types of digital processing and classification with high precision.

27. Since the technology of GIS was based upon integration and a multi-level approach—involving mainly computer science, mathematics, planning and Earth science—remote sensing had become an important source for information that was essential for database establishment. Remote sensing had thus become the cornerstone of GIS applications and information technology.

28. GIS, which was based on the use of computers and applied software, was now considered the new technology for database establishment. Those databases consisted of different thematic maps of various spatial resolutions and attributed physical parameters. Based on the processing and analysis of the databases, solutions and choices were obtained and used in planning and modelling for natural resource management.

3. Natural resource management using the geomatic approach

29. The presentation on this subject provided an overview of the image-processing and data analysis approach for natural resource management through case studies on forest mapping and inventory and evaluation of soil erosion.

30. The first case concerned the utilization of Landsat TM images to establish forest maps. The approach adopted was based on photo-interpretation to obtain the required information. Several processing techniques were used: geometric correction, contrast enhancement and classification. Exogenous data (existing maps and field surveys) were also used to draw the final maps.

31. The second project utilized a combination of remote sensing and GIS techniques to develop erosion risk maps. The presentation focused on the methodologies used to generate thematic maps (temperature, run-off, soil, slope and exposure, land use and vegetation index) to be integrated with models for erosion estimation. The role of GIS in data analysis and management was also described.

4. Linear mixture modelling for vegetation mapping in dry lands

32. Mapping vegetation cover in dry lands posed a problem because of the high contribution of the soil to the background spectral properties of each pixel as a result of the low vegetation density. Mixed pixels were very common in such an environment because vegetation cover very rarely reached 100 per cent, making most pixels a mixture of vegetation, fine sediments (soils) and stones. Consequently, mixed pixels were the main cause of classification error in dry lands because image classification techniques assumed pixels to be pure. Unfortunately, that was not the case in dry lands where the classes of land cover were continuous rather than discrete. Furthermore many classes that were commonly defined as "urban" or "bare rock" were often spectrally heterogeneous, being a mosaic of numerous spectrally different materials and because rock outcrops exhibited topographies that led to variations in illumination. The result of such within-class heterogeneity was that classes with high variance suffered significant levels of misclassification. Furthermore, classification approaches could not provide objective vegetation maps because of the human intervention required in highly interactive processes such as spectral class definition.

33. It was evident that a method for mapping vegetation in dry land areas was needed that: (a) used the maximum amount of spectral information; (b) took into account the fact that most pixels were mixtures; and (c) neutralized the effects of the atmosphere, as well as problems of illumination and observation geometry. The linear mixing model using the concept of spectra satisfied all of those conditions.

34. In the presentation, the assumptions underlying linear mixing were discussed and a solution to the linearity of the mixing problem was proposed. A report was then made of the results when the procedure was applied to a number of TM images to generate different maps of the study area.

5. Evaluation of texture-based classification of a single synthetic aperture radar image

35. In the presentation on this subject, a comparison was made between two classification methods. The first method used a combined classification based on textural and radiometric information and the second used only radiometric information. Textural analysis was made by using the gray level co-occurrence matrix (GLCM), for which contrast, entropy, homogeneity, correlation, local homogeneity, directivity and uniformity were used.

36. It was demonstrated that a significant improvement in classification accuracy occurred if textural features were used as additional inputs to the radiometric information. However, neither method was able to discriminate between targets situated in shaded areas and areas directly exposed to the radar signal. The overall classification accuracy obtained using the GLCM method was 55 per cent, a significant improvement over the classification using only radiometric data, which gave an accuracy of 35 per cent. Results could be improved if the effect of macro relief was eliminated in order to isolate the micro relief that characterized textural information.

6. Combined classification of a SPOT-XS image using textural and multi-spectral information

37. Texture analysis played an important role in image processing, image classification and in the interpretation of remotely sensed data. The GLCM approach was one of the most popular statistical methods used in practice to measure the textural information of images.

38. The objective of the study was to combine textural and multi-spectral information in order to carry out a combined classification using a SPOT-XS image.

39. A combined cartographic procedure, based on a semi-automatic approach using the procedures of supervised classifications of the same scene in SPOT-XS, were applied to the Foum Tillicht district in the eastern High Atlas of Morocco.

40. The combination of textures on a SPOT-XS image and spectral properties on the same SPOT-XS image made it possible to improve supervised classifications, resulting in better discrimination of the structures and geological formations.

41. Combining a GIS of maps based on existing cartographic data, the digital elevation model (DEM) and the information obtained made possible a geological inventory of the area and led to a significant improvement over existing maps.

42. The texture of the SPOT-XS image was related directly to the geomorphology and form of the relief. Thus, superposition of the geological map obtained in the study made it possible to present the geological map in block diagram form, producing a three-dimensional image of considerable use to geologists.

7. Role and retrieval of geophysical parameters in studying land surface processes

43. Anthropogenic activities had become a significant force affecting the functioning of the Earth system. Climate, the global cycles of carbon and water and the structure of natural ecosystems were all closely linked. Major changes in any one of those systems affected the others. Thus, there was a need to study and model the significant interactions of biological, chemical and physical processes that governed changes in the Earth system and were most susceptible to human influence. Satellite data sets provided a unique opportunity to retrieve many important geophysical parameters. In the retrieval scheme, understanding the physics of the problem was of paramount importance. The study presented dealt with the utility of satellite data in estimating surface albedo, surface emissivity, surface temperature and related physical parameters. Those parameters were derived using various methodologies. Algorithms had been used to estimate surface albedo by effectively utilizing satellite data information. An attempt had been made to derive narrowband and broadband emissivity. The concept of vegetation indices had also been studied as they were the inputs for estimating surface emissivity. The measurement of those parameters contributed to knowledge about physical surface temperature. Evapotranspiration, a significant component of both water balance and energy balance, was also estimated using satellite data. Overall, an effort was made to estimate land surface processes that were otherwise inaccessible from ground-based measurements.

C. Application of remote sensing in meteorology

Overview of systems of operational meteorological satellites in geostationary and polar orbit

44. It was stated that, for the past two decades, a fleet of operational meteorological satellites had been circling the Earth, providing a stream of invaluable data in support of operational meteorology and many other disciplines. An international network of satellites in geostationary orbit, stationed far above the equator, provided images of mid-latitudes and the tropics each half hour, day and night. Systems of satellites in lower orbits were flying around the Earth from pole to pole every 100 minutes, observing the planet twice a day with an extraordinary range of powerful sensors.

45. During that period, the applications of such satellites had grown far beyond the dreams of those who had established the systems more than 20 years ago. They had become essential, not only for meteorology, but also for climate monitoring purposes and for monitoring the health of the oceans, land surfaces and the planetary atmosphere. The range of applications was so large that it had become difficult to keep track of what the satellites could be used for. Few could have imagined, for example, that planned meteorological satellites would measure with high precision the speed and direction of the surface winds over the oceans of the entire planet or that the same satellite could be used to track migrating wildlife and to monitor vegetation growth. Even after becoming aware of those possibilities, the potential user might have no idea which instruments were used for a given purpose, how the data were processed to achieve the required information or which entity around the world was in a position to provide further information.

46. The global system of operational meteorological satellites included a constellation of at least five satellites evenly spaced around the equator in geostationary orbit and at least two satellites in near-polar orbits. Geostationary satellites flew at an altitude of about 36,000 kilometres and each had the capability to provide almost continuous imagery and communications support over a wide region of the planet.

47. Each satellite could generate full Earth disc images covering nearly one quarter of the Earth's surface, day and night. The polar orbiting satellites flew in much lower orbits, typically at around 850 kilometres, with the orbital plane at an angle of about 80° to that of the equator. Polar orbit satellites were designed to look down on the entire surface of the Earth every day. Satellites in polar orbit circle the Earth, passing above the North and South poles several times a day. As the satellite looped around the globe, the Earth seemed to rotate under the orbit. The satellite passed over the entire surface daily.

D. Personal computer-based digital photogrammetry

48. The introduction of digital photogrammetry had changed the world of photogrammetry completely. It was no longer necessary to use the expensive hardware components formerly required, if digital images were available. Only a scanner was required if traditional aerial photos were to be used. It was reported that the University of Hanover, in cooperation with the University of Düsseldorf, both located in Germany, had developed a software system that could carry out the following functions: measurement of image coordinates as input for block adjustment, bundle block adjustment, measurement of a digital stereo pair, generation of DEM by automatic image matching, filtering of elements not belonging to a DEM, generation of orthophotos, mosaics of orthophotos and the processing of DEM. The processing of DEM included the computation of contour lines, three-dimensional representation and more. The whole program system was personal computer (PC)-based and simple to handle. The whole world of photogrammetry was thus available on standard PCs with very little effort.

49. Photos were information about the imaged objects, but information without geometric reference was useless. Photogrammetry provided the three-dimensional reference for context information. For a long time, analog and analytical photogrammetry had dominated, both were proven techniques, but they required expensive instruments. Even standard PCs were now powerful enough to handle aerial or space images with full resolution, such that digital photogrammetric applications could be handled on simple PCs. The only hardware component needed for digital photogrammetry beside the computer was the image

scanner, if analog images needed to be used. To take advantage of the full accuracy range of the photogrammetry, special photogrammetric scanners were required because desktop publishing scanners were limited to an accuracy of approximately +/-50 µm, even if the resolution of the photograph might be higher.

50. The important advantage of digital photogrammetry was the possibility of automation. Automatic image matching was no longer time-consuming and was much faster than manual measurement of DEM.

51. All the steps required from the digital image to the final result were available in the SIDIP programme system, developed by the University of Hanover in cooperation with the University of Düsseldorf.

E. Hands-on remote sensing and geographic information systems at the General Organization of Remote Sensing

52. GORS was constituted in the Syrian Arab Republic in February 1986. Located in the outskirts of Damascus, GORS cooperated with governmental bodies, countries of Western Asia and international bodies. The Organization carried out studies and projects on remote sensing applications for geology, hydrology, hydrogeology, agriculture, urban planning, environment, meteorology and archaeology by utilizing Landsat and SPOT images and published on a regular basis a space atlas of Syria, a glossary of remote-sensing terminology in various languages and journals of remote sensing.

53. A major objective of GORS was to support sustainable development while safeguarding the country's environment. That required optimal management of natural resources, which in turn depended on the availability of reliable and timely information at the national and regional levels. Remotely sensed data played an increasingly important role as a source of the information needed for sustainable management of natural resources and for environmental protection. Through GIS, remote sensing data could be integrated with data from other sources to facilitate the efforts of resource managers, planners and policy and decision makers in obtaining the relevant information they needed. In order to facilitate such sustainable resource management in countries of Western Asia, GORS conducted courses and symposiums in remote sensing and GIS as applied to various Earth resource disciplines. The venue of the workshop, GORS, was a premier training institution in the region of Western Asia that had trained individuals from the Syrian Arab Republic and elsewhere over the last two decades. GORS was well equipped with state-of-the-art computing facilities such as sophisticated personal computers and workstations with modern peripherals and software for remote sensing and GIS. It also had laboratories for ground truth equipment. Participants at the workshop had the opportunity to familiarize themselves with the computer hardware and software available at GORS during hands-on sessions for satellite data reduction, processing and analysis, and applications.

54. In the hands-on sessions, special attention was drawn to a recent study of groundwater exploration by remote sensing in the Syrian Arab Republic, conducted jointly by GORS, Italy and the Food and Agriculture Organization of the United Nations. The study had indicated that the integration into GIS of data extracted from Earth observation satellites with those traditionally collected, coupled with selected field investigations and geological knowledge of the area under investigation, provided a powerful tool in the search for groundwater.

Notes

[1] *Report of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space*, chap. I, resolution 1, part I, sect. 1 (e) (ii), and chap. II, para. 409 (d) (i).

[2] *Official Records of the General Assembly, Fifty-fourth Session, Supplement No. 20* and corrigendum (A/54/20 and Corr.1), para. 52.